A 3.5 W OUTPUT, DIODE-PUMPED, Q-SWITCHED 532 nm Nd:YAG LASER PUMPED BY FIBER-COUPLED DIODE I, ASERS

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ABSTRACT

A single Nd:YAG laser crystal was pumped by three 1O-W fiber-coupled diode lasers. At 50 kHz pulse repetition frequency, average output powers exceeding 11 W of continuous-wave 1064 nm, and 3.5 W of 532-rim were achieved. A folded three-mirror cavity which compensated for thermal lensing in the laser crystal was utilized. One arm of the cavity contained the Nd:YAG rod and an acousto-optical Q-switcher while the other arm contained a frequency -doubling nonlinear crystal. The 532 nm output beam quality was 1.5.

INTRODUCTION

Compact lasers with high wall-plug efficiency and with average output power and pulse repetition frequency of greater than 2 W and 50 kHz, respectively, are needed for laser communication from outer planets to the earth. Other requirements for such a laser include: single spatial mode beam quality, visible to near infrared wavelength, short (ns level) pulse width, simple thermal management and low pulse jitter. Lasers with above characteristics also have applications in material processing & testing, resistor trimming, wafer marking, ranging, spectroscopy, film writing, printing, displays, holographic, and medical instrumentation.

With fiber-coupled lasers the diode laser can be remotely located relative to the laser resonator. This feature facilitates removal of heat generated by high power diode pump lasers and reduces complications due to thermal gradients in the laser's mechanical assembly caused by the diode pump lasers. Also, alignment of the pump laser(s) with the resonator is simpler with fiber-coupled diode lasers. Recently, a number of continuous-wave (CW) [1-4] and pulsed [5-8] solid-state lasers pumped with cw diode lasers have been reported. In this research we developed a very compact laser with greater than 11 W of cw output at 1064 nm and 3.5 W of near diffraction-limited 532 nm second harmonic at pulse repetition frequency (PRF) of 50 kHz, with the highest known wall-plug efficiency. An end-pumped scheme was selected since, generally diffraction-limited output can be obtained more efficiently with end-pumped rather than side-pumped lasers. A true wall-plug efficiency of 2.3% was obtained. Higher efficiencies are expected in the future.

DESIGN

To achieve over 2-W of 532 nm average output at pulse repetition frequency of 50 kHz, greater than 20 W of 809 nm pump laser power is required, At tens of Watt pump power levels, a significant thermally-induced lensing and birefringence is generated in most solid-state laser materials. Nd:YAG laser crystal was selected as this laser's active medium since it has lower thermal lensing coefficient than Nd:YV04 and significantly higher thermal fracture strength than Nd:YLF.

The approach proposed by Magni was followed to design the laser resonator [9], "l'he radii of curvature of the mirrors were selected such that the resonator supports a single-spatial-mode with large mode volume, has high alignment stability, compensates for the thermally-induced lens, and has low sensitivity to focal length fluctuations of that lens. A commercially available software (Paraxia™, Genesse Software) was used to model the resonator. With 27 W of continuous-wave 809 nm power focused to a spot size of 0.4 ± 0.05 mm in the crystal, two different resonators were identified to satisfy the requirements mentioned above: (1) a piano-concave resonator with the concave mirror having a radius of curvature of 100 cm, (2) a convex-concave resonator consisting of a 12 cm radius of curvature convex mirror and a concave mirror with radius of curvature of 100 cm. The piano-concave mirror was used in this set up due to availability of the mirrors.

EXPERIMENTAL SETUP

Figure 1A shows a schematic of the folded laser resonator. The frequency-doubled (green) intracavity beam is confined to a region of the cavity containing only the frequency-doubler. The folded resonator has been used earlier for both end-pumped and side-pumped configurations [10-12]. In this research, the output beam of each of the three 1O-W fiber-coupled diode lasers (SDL-3450-P5) was partially collimated by an 8.6 mm focal length lens combination (Newport Research, F-L20) to a total beam diameter of 1.8 cm, measured 1 cm away from the lens. Following the approach by Fan et al [13], the three closely-spaced collimated beams were focused with an efficiency of 90% into one end of the Nd:YAG crystal using a single 2.35 cm focal length aspheric lens (Melles Griot, 01 LAG 115). The pump-spot radius of the focused beam at the laser crystal was 0.43 mm. Both end faces (7 mm in diameter) of the 7-mm long Nd:YAG rod were anti-reflection coated, The output wavelength of the lasers (at 25°C) ranged from 808 nm to 811 nm. The temperature of the crystal was maintained at 17 'C. The 100-cm radius of curvature concave input mirror had AR coating at 809 nm on the entrance face, and high reflectance (HR) at 1064 nm on the second surface. The flat fold mirror was HR-coated at 1064 nm and had high transmission at 532 nm second harmonic for 45° angle of incidence. The flat end mirror had dual HR coating at 1064 nm and 532 nm. The cavity length was 10.5 cm producing a fundamental spot size of approximately 0.52 mm at the input mirror.

To avoid the need to generate high voltages for electro-optical Q-switching, an acousto-optical Q-switcher was selected. The acousto-optical Q-switcher crystal had AR coating at 1064 nm on both surfaces. The Q-switcher was driven at 80 MHz center frequency with 1.4 W of RF power. It was always operated at above 10 kHz to avoid damage to the resonator optics and intra-cavity elements. A dual-wavelength AR-coated KTP ($KTiPO_4$) crystal was used for frequency-doubling.

RESULTS

Figure 2 illustrates the second harmonic and fundamental average output power, at 50 kHz pulse repetition frequency (PRF), as a function of the incident cw pump power. The cw 1064 nm and pulsed 532 nm lasing thresholds were 2.1 W and 2.5 W, respectively, With full pump power (30-W), over 11.7 W of cw 1064 nm power and 3.5 W of pulsed 532 nm power were obtained. Approximately 21.1 W of the total pump power was absorbed in the laser crystal. The optical-to-optical conversion efficiencies were 55% and 16.6% for 1064-nm and 532-rim, respectively.

Figure 3 shows a plot of the second harmonic average output power and laser pulse width as function of the PRF. The true wall-plug efficiency of the laser, considering all electrical power supplied to the pump diode lasers, the Q-switcher, and those for heat removal from the diode lasers and laser crystal, was 2.3910.

The ratio of the far-field beam diameter to the diffraction limited beam diameter, calculated for the same cavity waist, provides a measure of laser output beam quality The beam quality was a function of the pump power since the focal length of the thermally induced lens, and therefore the Fresnel number for the cavity, varied with pump power, The measured cw 1064 nm beam quality (M2) factor [14] was 2,2. The Q-switched 532 nm output beam quality was approximately 1.5 times the diffraction limit.

Acknowledgment: This work was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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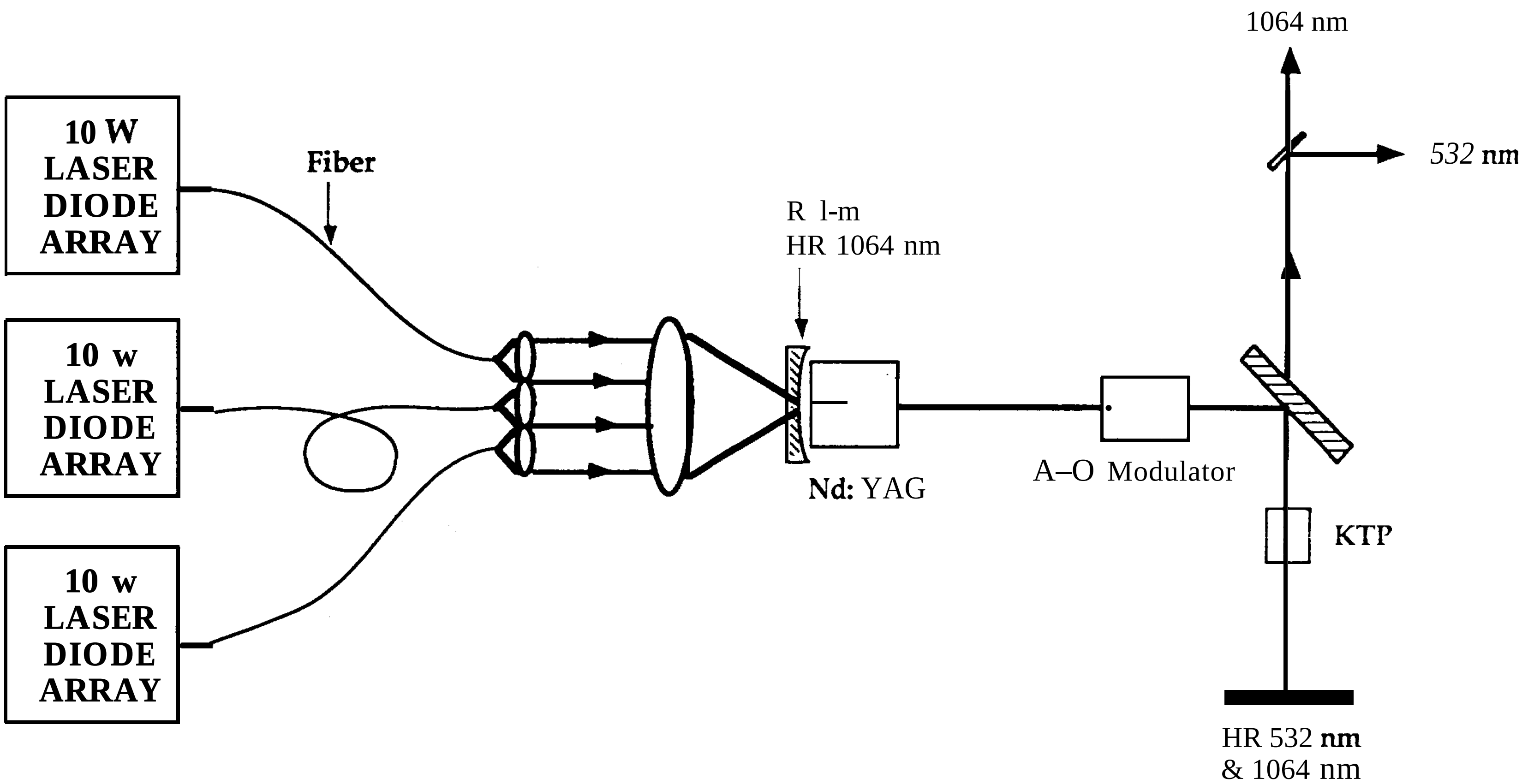

Figure 1. Schematic of the Experimental Setup

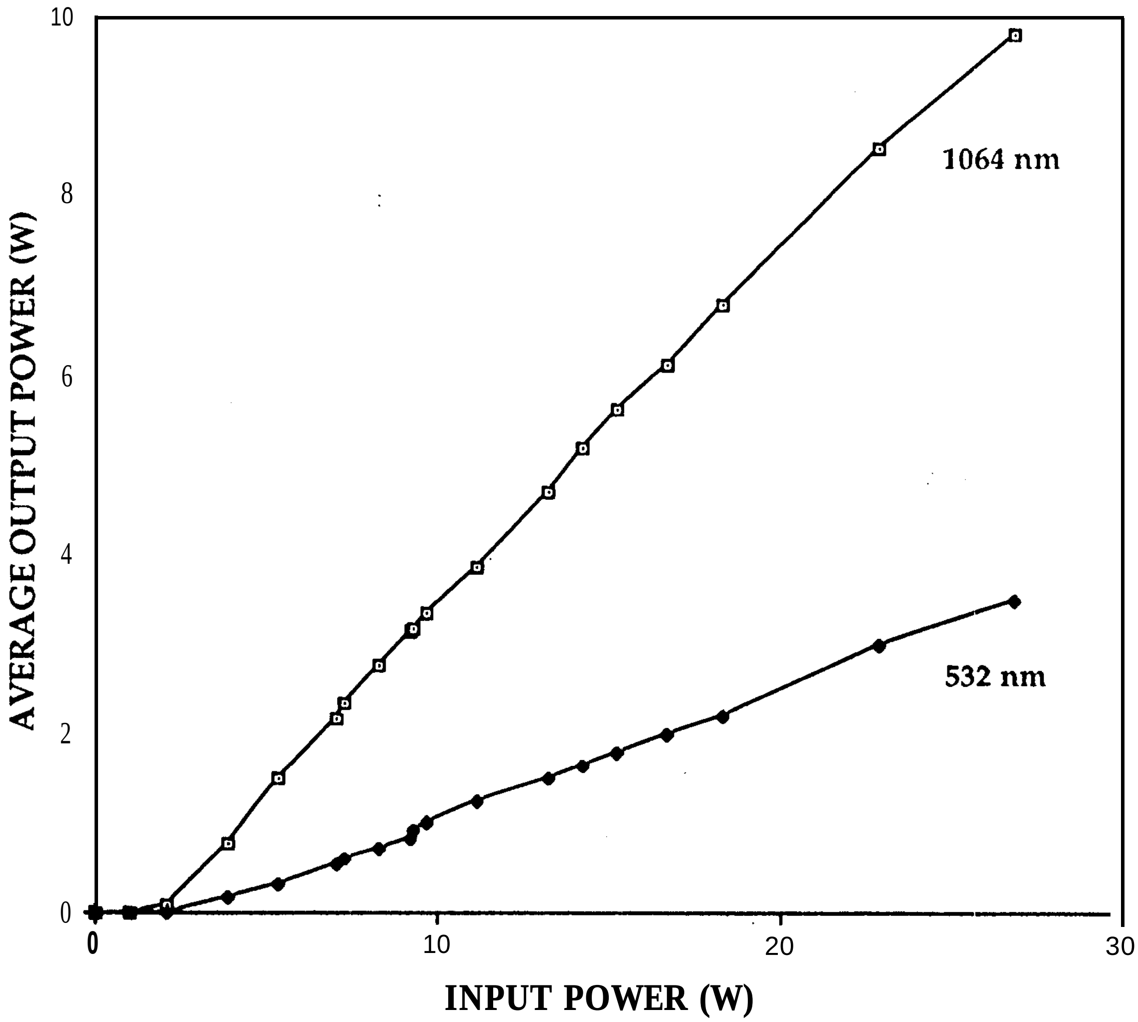

Figure 2. Continuous-Wave Output Power at 1064 nm and Pulsed 532 nm Output as a Function of the Incident Pump Power

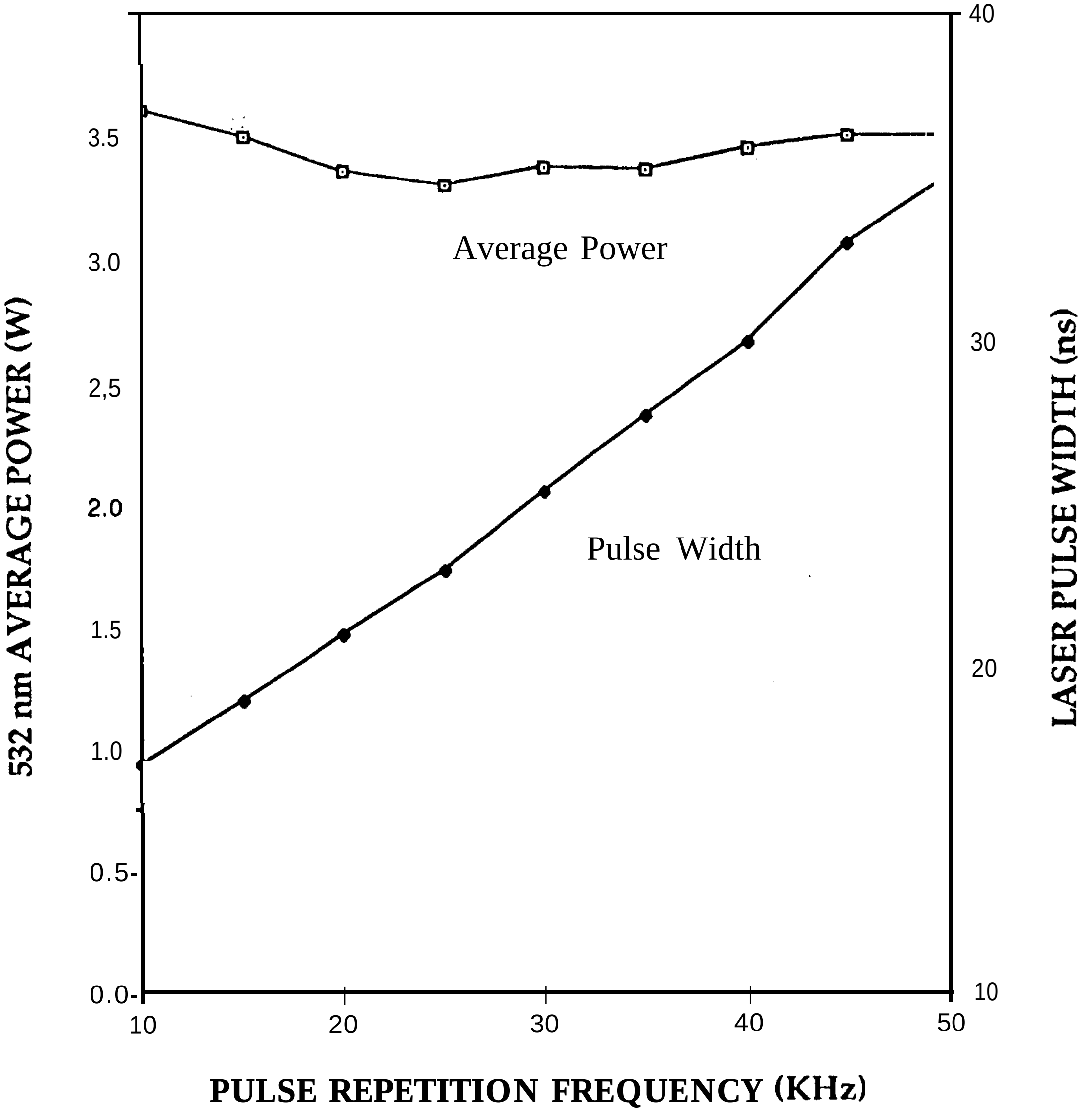

Figure 3. Average Output Power at 532 nm and Laser Pulse-Width as a Function of the Q-switch Pulse Repetition Frequency